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Development Strategy for Advanced Fuels For LWR Operations with Enhanced Accident Tolerant Features

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Vision, Mission and Near-Term Goals

Vision:
LWR fleet with enhanced accident tolerance providing a substantial fraction of the national clean energy needs

Mission:
Develop advanced fuels and non-design intrusive reactor system technologies(e.g. instruments, auxiliary power sources) with improved performance, reliability and safety characteristics during normal operations and accident conditions

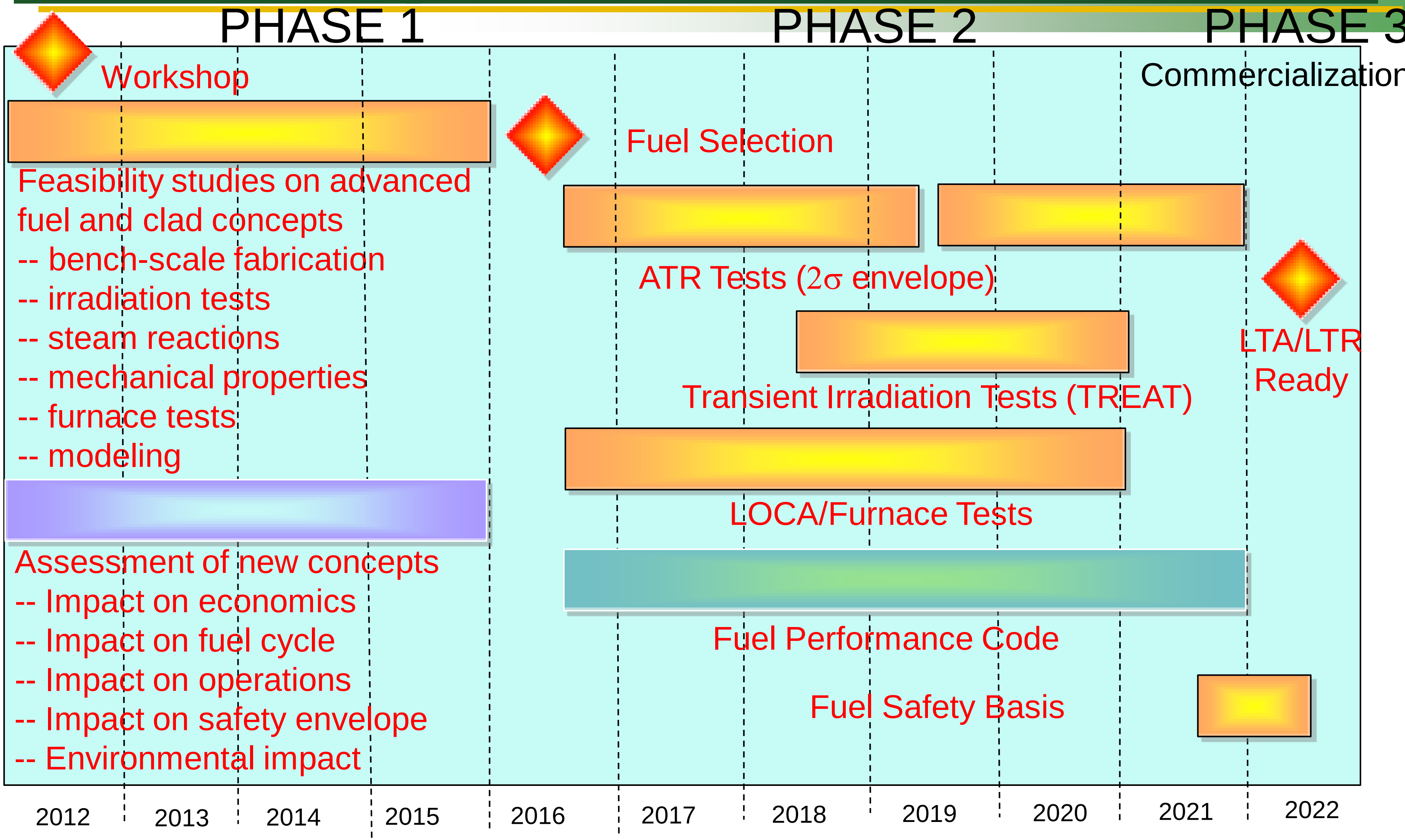
10-year Goals
- *Insert a LTA into a operating commercial reactor*
- *Demonstrate non-intrusive technologies that enhance safety (e.g. instrumentation with enhanced accident tolerance)*

Definition of Fuels with Enhanced Accident Tolerance

Fuels with enhanced accident tolerance are those that, in comparison with the standard UO_2 – Zircaloy system, can tolerate loss of active cooling in the core for a considerably longer time period (depending on the LWR system and accident scenario) while maintaining or improving the fuel performance during normal operations.

To demonstrate the enhanced accident tolerance of candidate fuel designs, metrics must be developed and evaluated using a combination of design features for a given LWR design, potential improvements and the design of advanced fuel/cladding system.

Notional schedule
(National Labs + Universities + Industry)



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What are the major issues to be addressed for the attributes?

Improved Reaction Kinetics with Steam
- -Heat of oxidation
- -Oxidation rate

Slower Hydrogen Generation Rate
- -Hydrogen bubble
- -Hydrogen explosion
- -Hydrogen embrittlement of the clad

Improved Fuel Properties
- -Lower operating temperatures
- -Clad internal oxidation
- -Fuel relocation / dispersion
- -Fuel melting

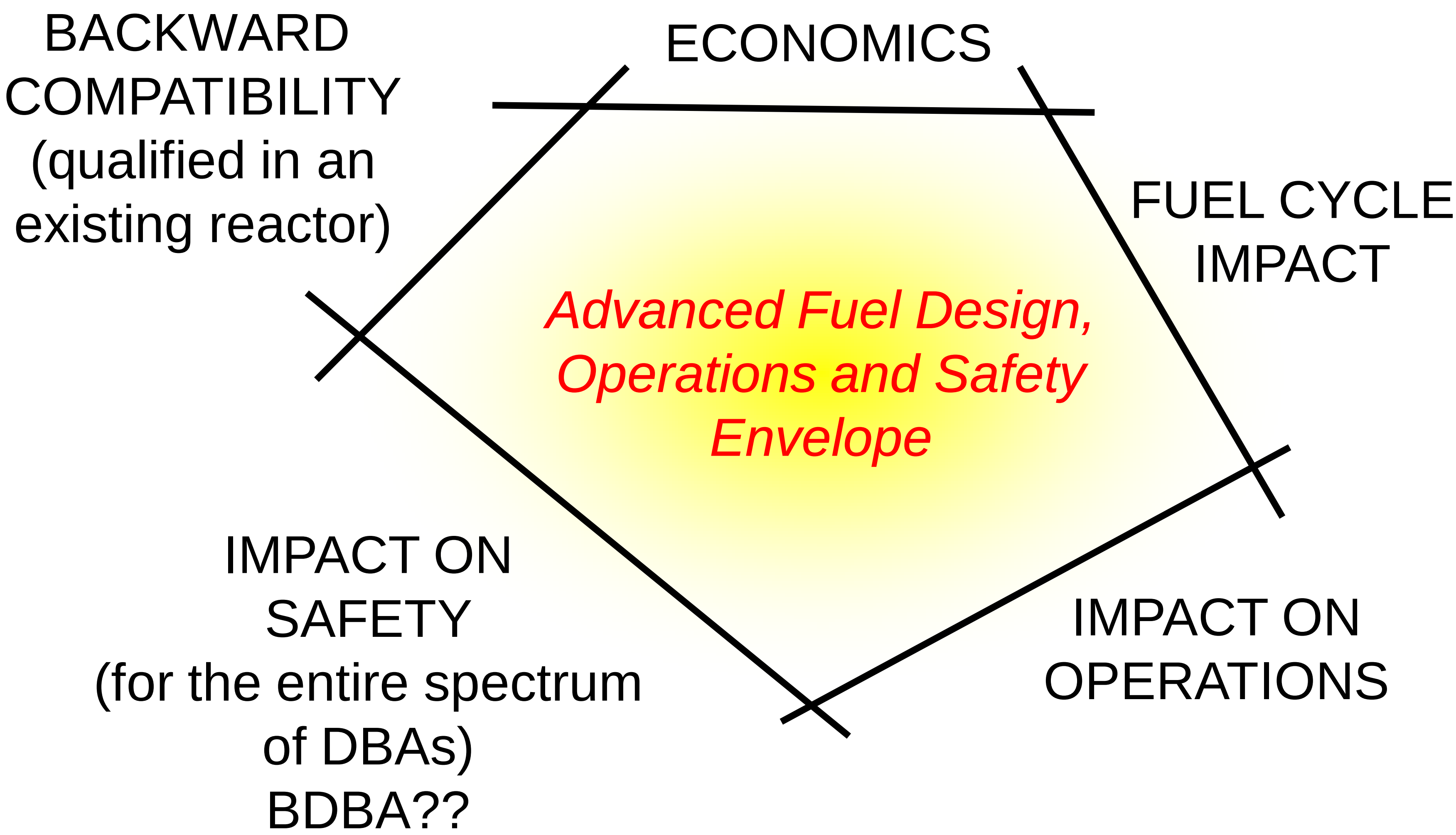
High temperature during loss of active cooling

Improved Cladding Properties
- -Clad fracture
- -Geometric stability
- -Thermal shock resistance
- -Melting of the cladding

Enhanced Retention of Fission Products
- -Gaseous fission products
- -Solid/liquid fission products

Based on these safety-related issues, metrics for quantifying the enhancements in accident tolerance must be developed in conjunction with the safety features of a given LWR design and based on specific accident scenarios.

Constraints on new fuel designs

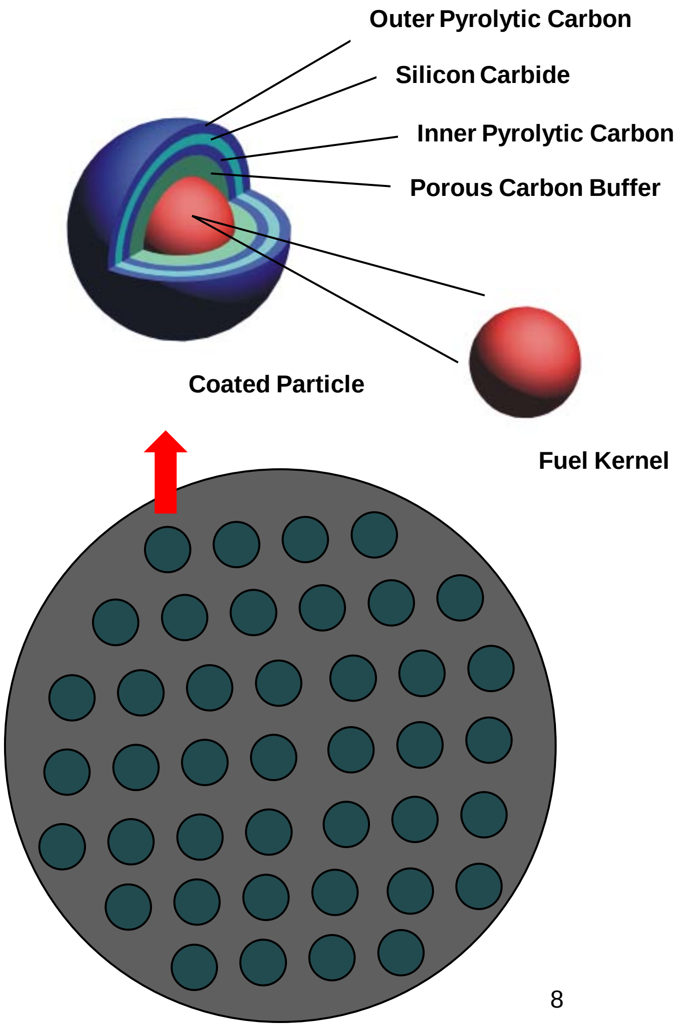


Economics should be considered within the big picture

- Economic Impacts: It is likely that the “fuels with enhanced accident tolerance” will cost more
- How much additional cost will be tolerable to utilities ?
- Can some of the increase in cost be offset by other cost reduction ?
    - Higher burnup – longer cycle – smaller volume of used fuel?
    - Higher power density – power upgrades?
    - Reduction in reliability requirements on or total elimination of some safety systems?
    - cost reduction during wet and dry storage?

The impact of the new fuel on the overall fuel cycle must be considered.

- Enrichment
  - Small increases beyond 5% (SS cladding with UO_2 fuel)
  - Larger increases in enrichment (up to 20%) (microencapsulated fuels)
- Storage/Transportation/Disposal
  - Storage behavior of new fuels and cladding (wet and dry storage)
  - Impact on repository performance
- Impact on reprocessing if implemented in the next 30 to 40 years



The new fuel should not shrink the currently established operating envelope.

- Maintain or expand the cycle length
  - Some concepts require new design for burnable poisons
  - Increased enrichment
- Maintain or improve on reactivity coefficients and safety margins
  - Void coefficients, doppler, etc…
- Maintain or improve on DNB margins
  - Fuels that can partially operate past DNB ??
- If a new assembly design is needed, it must operate within the thermal-hydraulic constraints of the primary loop design.
  - Compatible with control rod, and safety rod designs

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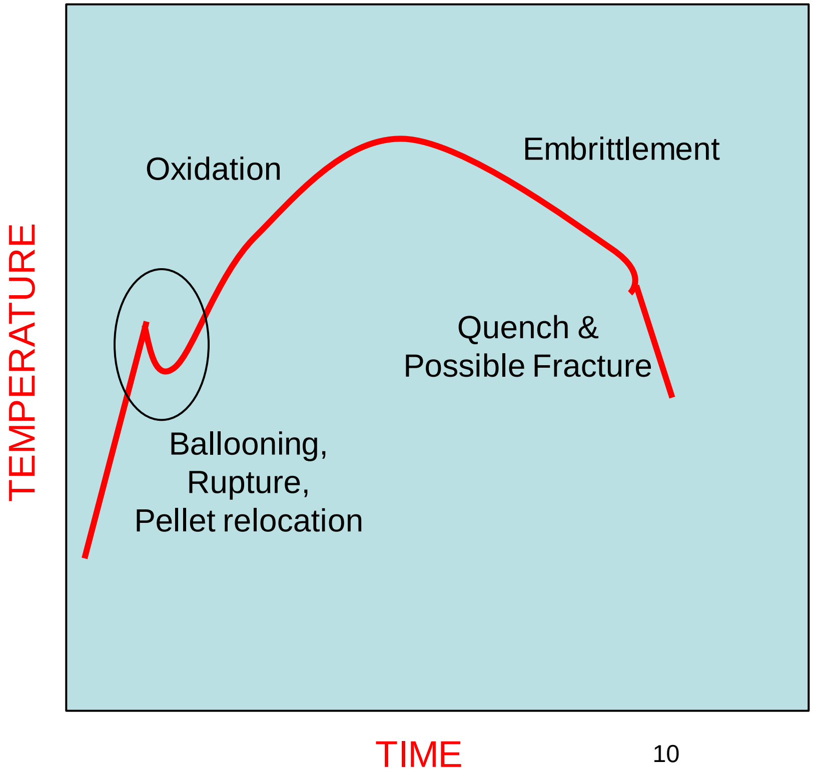
The fuel should not negatively impact the response to design basis accidents (DBAs)

- Consider all accidents
  - Reactivity Insertion Accidents (RIA)
  - Loss-of-coolant accidents (LOCA)
  - Station blackout
  - Anticipated Transients without Scram (ATWS)
  - Others
- Current design-basis LOCA limits
  - Maintain coolable geometry
  - Temperature ≤ 1200 C
  - Oxide layer < 17% clad thickness
  - High burnup fuels?



Development and demonstration of new fuels require new infrastructure

- Irradiation testing (steady state, operational transients, design-basis transients, failure thresholds)
- Furnace testing for high temperature conditions with irradiated samples (Hot Cells)
  - Steam reactions
  - Fuel behavior, fission product release
- Mechanical testing of cladding after irradiation and extended exposure to steam while in contact with fuel
- Characterization/PIE of failed fuel or seriously damaged fuel
- Capability to fabricate the new fuels eventually at large quantities for qualification

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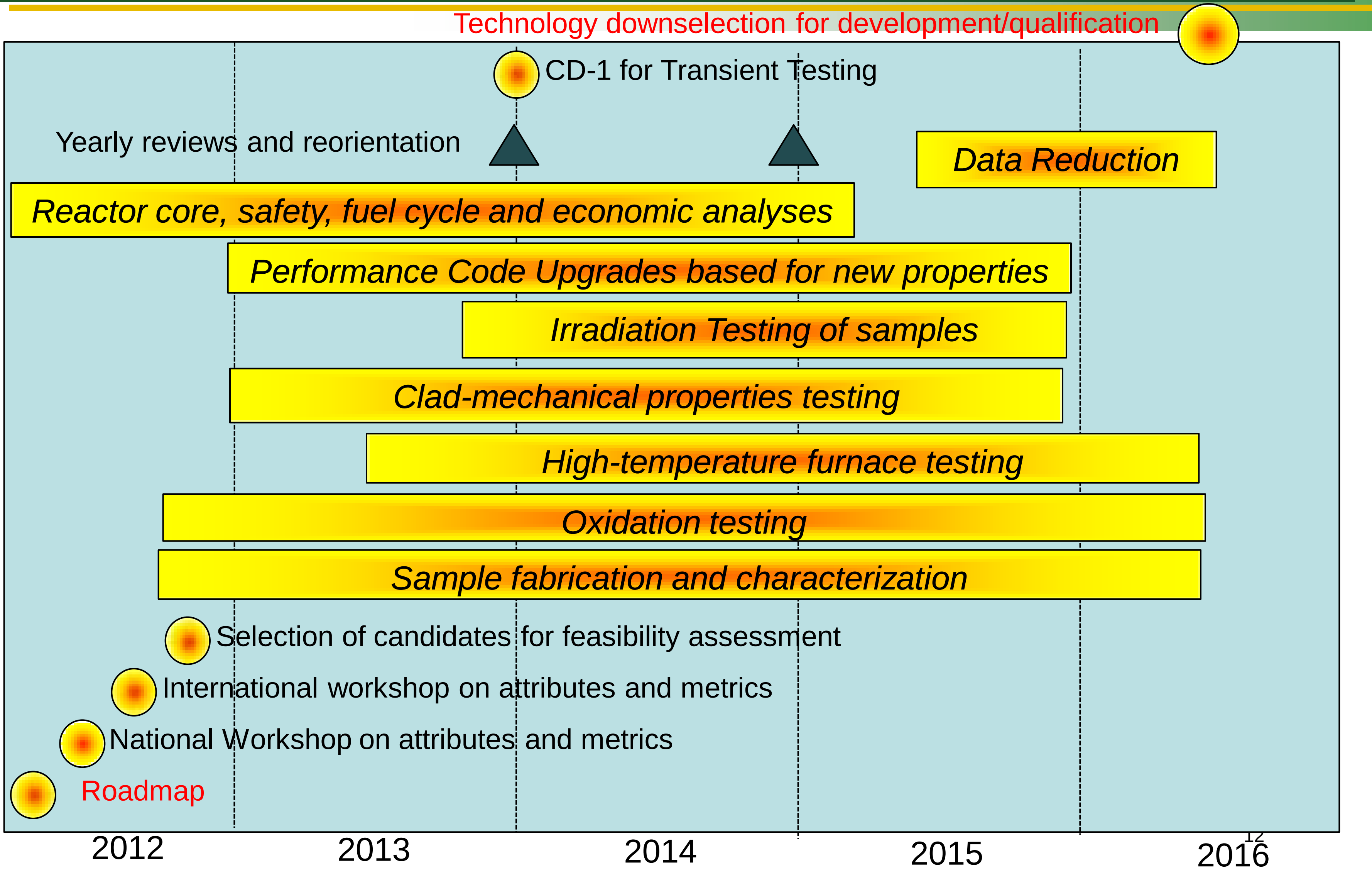
Feasibility phase – Major activities and milestones



Interfaces for development of LWR fuels with enhanced accident tolerance

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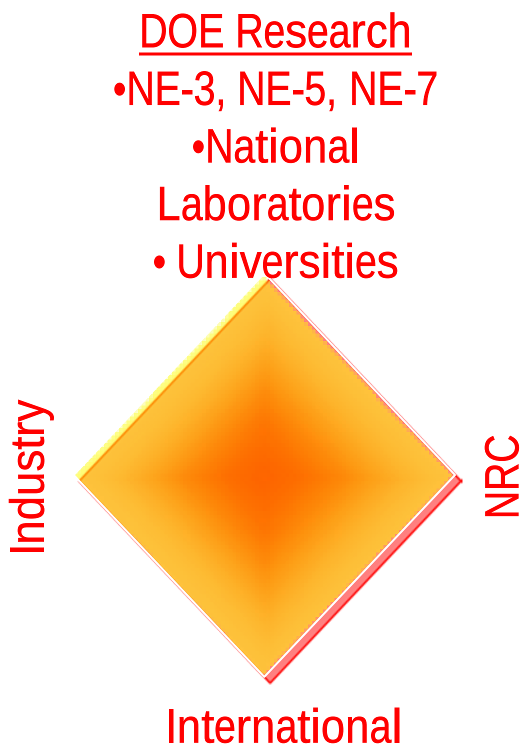
- Integrated program across NE
  - NE-5: fuel development
  - NE-7: supporting technologies (e.g. reactor design, instrumentation, materials, safety and operations analyses, modeling and simulation, etc…)
  - NE-3: infrastructure
- Strong collaborations with industry is NECESSARY
  - Campaign industry advisory group has been very useful
  - Leverage LWRS –Industry interactions
- Working with NRC in defining the enhanced accident tolerance, its attributes and associated metrics will be very USEFUL
  - Working group with NRC-Research
- International engagement in defining accident tolerance, its attributes and associated metrics will be ESSENTIAL



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FY12 IRPs on Accident Tolerance

NE-5 and NE-7 will each solicit an FY12 IRP related to advanced LWR systems with enhanced accident tolerance.

NE-5 IRP

- Focus on advanced fuels for currently operating reactors and those with design certifications (Gen III+).
- Advanced <u>materials and/or fuel-cladding concepts</u> that would improve performance and safety, both during reactor service and during long-term storage.
- Improvements to the nuclear fuel and cladding system may be accomplished by many possible methods including: design, materials, or combinations of the two.
- Feasibility testing and analyses

NE-7 IRP

- Focus on advanced LWR concepts (beyond Gen III+) and associated fuel designs.
- Whole synergistic design (structures, components, materials including fuel and cladding, passive features, etc.) that would make the reactor inherently safe
- Improvements to all GEN IV performance goals including sustainability (fuel use/waste minimization), economics, proliferation resistance and physical protection
- Conceptual design

Summary and Conclusions

- A three-phase approach for commercialization of the LWR fuels with enhanced accident tolerance is defined
  - Feasibility (industry participation with limited cost share)
  - Development and qualification (industry participation with cost share)
  - Commercialization (industry)
- The scope is focused on existing reactor designs (NE-5) and future designs (NE-7)
- Other advanced reactor concepts (SFR, NGNP) already addressing passive safety as part of the baseline R&D program.